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Parametric Analysis of Sound Transmission Loss in a Rectangular Duct Attached with Resonator Silencer

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ABSTRACT

Noise is an existing problem that exist in the environments produced from vibrating sources. In general, the common solutions for noise control are: (1) redesigning the system the system for instance increasing wall thickness or stiffening structures, and (2) adding additional damping in acoustic systems to dissipate sound energy such as the use of resonator silencers. However, the latter is more practical because it does not concern about the complexity of the design and modification cost. In this paper, the application of a single resonator silencer to reduce sound pressure levels and increase transmission loss of a rectangular duct is investigated. The application is further expanded by attaching multiple resonator silencers to study its efficiency. Two types of resonator silencers were analyzed namely quarter wavelength tube (QWT) and Helmholtz resonator (HR), where the sound pressure level and transmission loss were determined by finite element analysis using ANSYS. The first outcomes show that a single HR displays more efficiency in the reduction of sound pressure levels compared to a QWT over a wide frequency range. Subsequently, as the number of resonator silencers increased, the transmission loss was found increase with the sound pressure level decreased simultaneously. Overall, it can be concluded that HR is more effective over a wide frequency range and multiple resonator silencers can increase the transmission loss of rectangular duct.

Keywords: Noise attenuation, passive control, transmission loss, Quarter Wavelength Tube, Helmholtz resonator

1. INTRODUCTION

Noise is usually defined as unwanted sound which depends upon the listener or the circumstances. In particular noise in ducting systems can cause various effects including distress, annoyance and disturbance to humans [1]. For example, noise can cause distraction to people while work and cause them to lose focus. If not controlled, it can also affect human sleep time. All of these things can cause people to feel stressed and eventually lead to physical illness or worse such as high blood pressure and heart disease [2,3].

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Therefore, few engineering noise control methods have been developed to reduce the noise inherent especially in ducting systems [4–6]. Among these control methods, the passive technologies such as absorptive silencer (porous materials) and resonator silencers are usually the first alternative considered in industrial noise control practices. Of these two, absorptive silencer has received more attention due to their ability to reduce noise at mid and high frequencies [7]. Despite the attention received by absorptive silencer, resonator silencer has much more advantage over other noise control methods because it does not require energy to function, and it has no acoustic absorption material in the device. This is in contrast to absorptive silencer which rely heavily on the use of acoustic absorbent materials where they may be expensive and not durable enough [8]. Moreover, resonator silencer can also be used at certain frequencies where porous materials are difficult to use [9].

Basically, a resonator silencer works by providing a high reactive impedance causing the incident acoustic wave to bounce upstream, and this causes a mismatch impedance to occure which can eventually attenuate noise. There are many types of resonator silencers in use, with quarter wavelength tube (QWT) and Helmholtz resonator (HR) being the most popular. Some common applications of resonator silencers are mufflers, noise control by enclosures, fan noise reduction and reduction of sound radiation [10–13]. However, it is generally known that the disadvantage of this resonator is that it can only perform on limited bandwidth frequency [14].

Due to this shortcoming, improvements in the performance of resonator silencer have become a priority for researchers by considering various approach. With the advancement of technology, it has impacted the research, development and application of resonator. This can be seen from several review papers that have discussed topics related to resonator silencer configuration and applications [15–17]. For example, a study by Lane et. al who using the walls of rocket fairing structure as acoustic resonators to control noise in spacecraft [18], the use of tunable quarter-wavelength resonators to attenuate axial fan blade noise [19] and using single and coupled tube resonators embedded to design a sound absorbing wall [20]. There are also several studies with respect to resonator silencer by using experiment [21,22]. However, the study of resonator silencer by using experiment requires large cost and time consuming compared to finite element analysis, where prediction and analysis can be done in short time due to the computer speed in processing getting faster.

This paper aims to evaluate the sound pressure levels and transmission losses for rectangular duct system with resonator silencers installed, such as QWT and HR using finite element analysis (FEA). The analysis of the study included using multiple resonator silencers to reduce surplus noise in ducting. The outcomes are expected to revolutionize the current performance of resonator silencers over a broad frequency range, therefore improve their versatility and effectiveness in noise control of ducting system.

2. DESIGN MODEL

In this study, a comprehensive acoustic model of a rectangular duct with attached resonator silencer was developed using commercial ANSYS Workbench software. Important features of the numerical acoustic model include speed of sound, density, fluid velocity and dimensions of model. Figures 1 and 2 display appropriate models for quarter wavelength tube and Helmholtz resonator silencer attached to rectangular duct, while the parameters for both models are tabulated in Table 1.

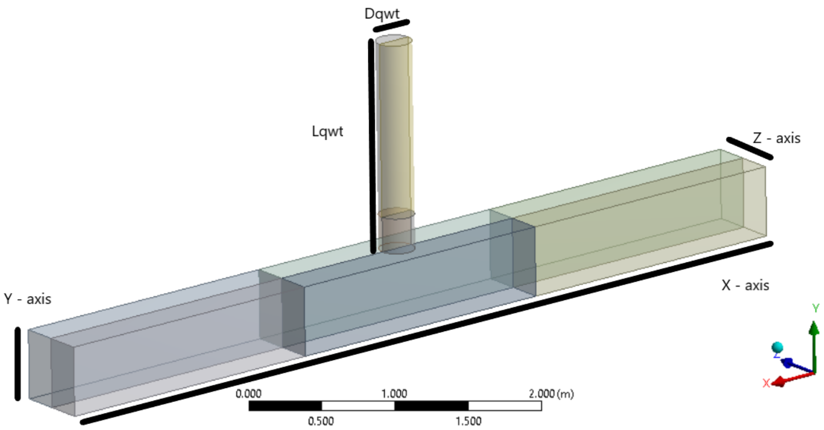

Figure 1. Quarter-wavelength tube attached to rectangular duct.

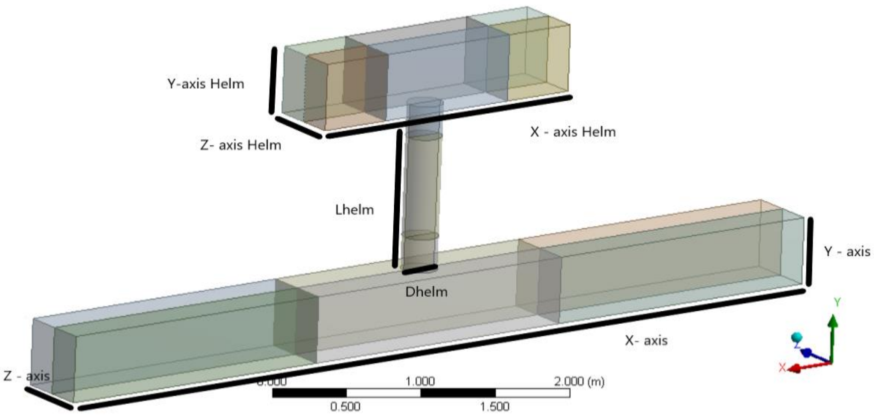

Figure 2. Helmholtz resonator attached to rectangular duct

Table 1 Parameters Used in the Analysis of Rectangular Duct with Quarter Wavelength Tube and Helmholtz Resonator

Description	Parameter	Value	Units
Z-axis main duct	Z – axis	0.1	m
Y-axis main duct	Y – axis	0.1	m
X-axis main duct	X – axis	2	m
Speed of sound	c_0	346.25	m/s
Density of air	ρ_0	1.225	Kg / m^3
Velocity at air inlet	u_1	0.001	m / s
Quarter Wavelength Tube (QWT)			
Diameter	Dqwt	0.05	m
Length	Lqwt	1.5	m
Helmholtz Resonator (HR)			
Diameter	Dhelm	0.05	m
Length	Lhelm	1.25	m

3. ANSYS SIMULATION

In model geometry of ANSYS Workbench, the assignment for all solid geometry parts is defined as air (acoustic region). Fluid path is created in construction geometry to generate sound pressure levels along a rectangular channel. From the meshing analysis, the computation FEA generates the tetrahedral elements in the study as shown in Figure 3. The reason for this element to be chosen is due to the difficulty in ANSYS Workbench to accommodate a mixture of mesh methods such as mesh refinement and sweeping. The model is divided into specific solid sections for different element sizes.

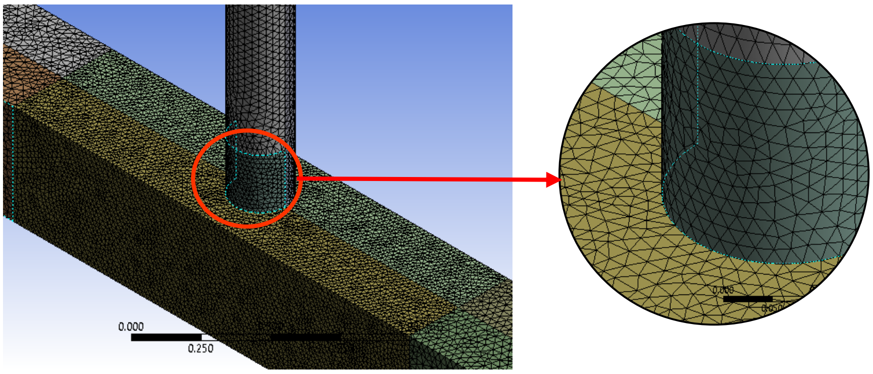

Figure 3. ANSYS Workbench model of a rectangular duct with tetrahedral elements.

3.1 Harmonic Acoustics

The analysis system used to solve the acoustic problems in the study was Harmonic Acoustics with the full method was applied to calculate the frequency response of the system. The parameter data as shown in Table 1 were set in harmonic acoustics to obtain the solution. Figure 4 shows additional parameters such as surface velocity, radiation boundary and port are added under the harmonic acoustics analysis. The frequency range was set from 0 Hz to 300Hz with a solution interval of 300. The upstream inlet provides acoustic excitation as a surface velocity of 0.001 m/s. In order to achieve anechoic termination, acoustic radiation boundaries were selected at the inlet and outlet faces of the main channel.

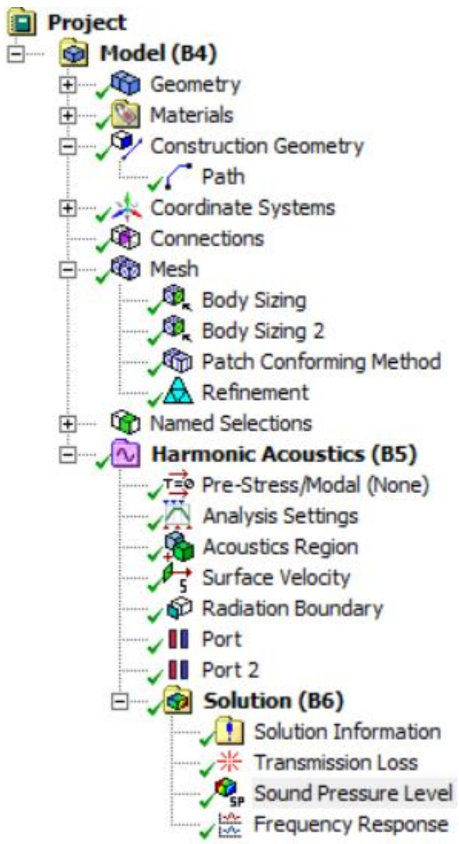

Figure 4. Project parameters used in ANSYS Workbench.

3.2 Solution Procedure

There are several metrics that can be used to evaluate the acoustic performance of resonator silencer. Among those used in this study are sound pressure level, transmission loss and frequency response as can be seen in Figure 4. From these metrics, natural frequencies, sound pressure level and transmission loss in the frequency range are calculated. In order to identify sound pressure along a rectangular duct, the scoping method is used by defining the path in X – axis to calculate the results.

4. RESULTS AND DISCUSSION

4.1 Effect of Resonator Silencers

Figure 5 shows the frequency response plots of the sound pressure level (SPL) at the outlet of the resonator silencer elements. It can be clearly seen that the SPL for quarter wavelength tube (QWT) decreases significantly at the frequencies of 60 Hz, 179 Hz and 298 Hz compared to Helmholtz resonator (HR) where it dips slightly at 20 Hz, 123 Hz and 240 Hz. These frequencies are known the natural frequencies of the system, where a drop in SPL indicates that the frequency of QWT is tuned to the natural frequency of the system [23]. From Figure 5, it also can be seen that the area under graph of the Helmholtz resonator silencer is smaller compared to the quarter wavelength tube. This demonstrates that the Helmholtz resonator silencer is effective in attenuate noise in the duct system over the broad frequency range.

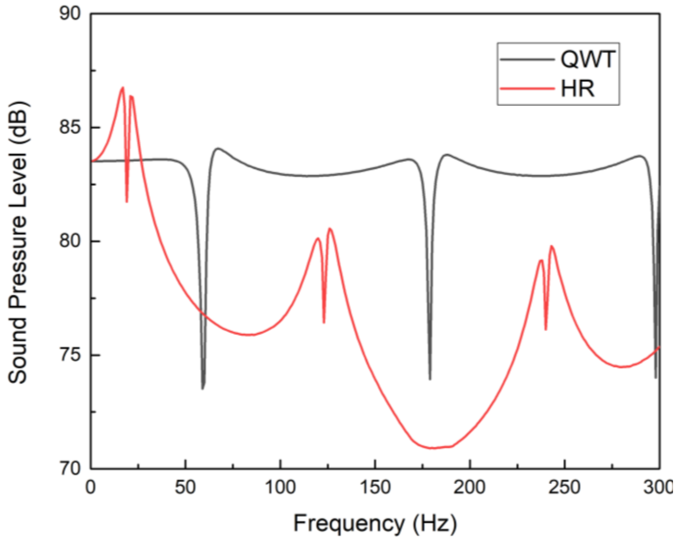

Figure 5. Comparison of sound pressure level for single resonator silencer.

Meanwhile, Figure 6 shows the comparison of the transmission loss results between QWT and HR. Obviously, it can be seen that the transmission loss of each type of resonator silencers approaches maximum value at different frequencies [24]. These frequencies are similar to the frequencies observed on the dip of SPL as shown in Figure 5. In this case, the frequency at which the maximum transmission loss is therefore known as the natural frequency.

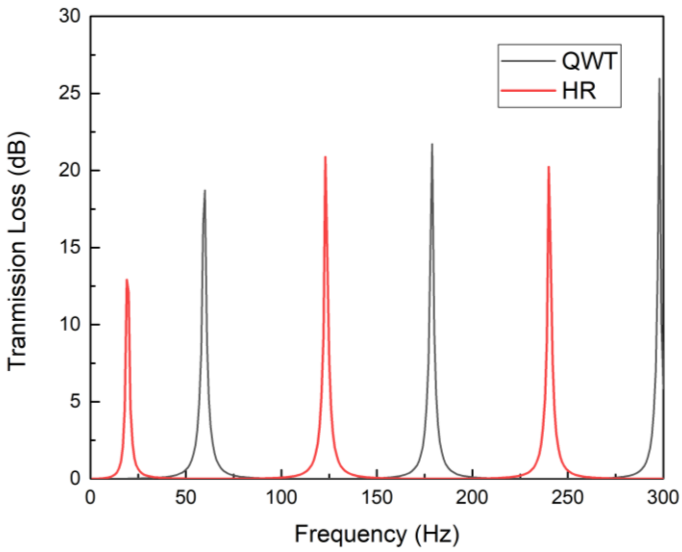

Figure 6. Comparison of transmission loss for single resonator silencer.

Figure 7 shows the sound pressure level in the duct system with attached resonator silencer at the first natural frequency where the transmission loss is high. As been mentioned in the previous result, the first natural frequencies of QWT and HR were to be happened at 60 Hz and 19 Hz, respectively. The results of sound pressure level show that both resonator silencers show the highest value in the device, thus verifying that the incident wave reflects upstream and the occurrence of high reactive impedance [24]. From these results also, it can be concluded that the downstream from the QWT and HR is constant as there is no impedance change. However, between the inlet of the duct (left side) and the QWT provides a slight impedance to the incident acoustic wave where it reflects back towards the inlet.

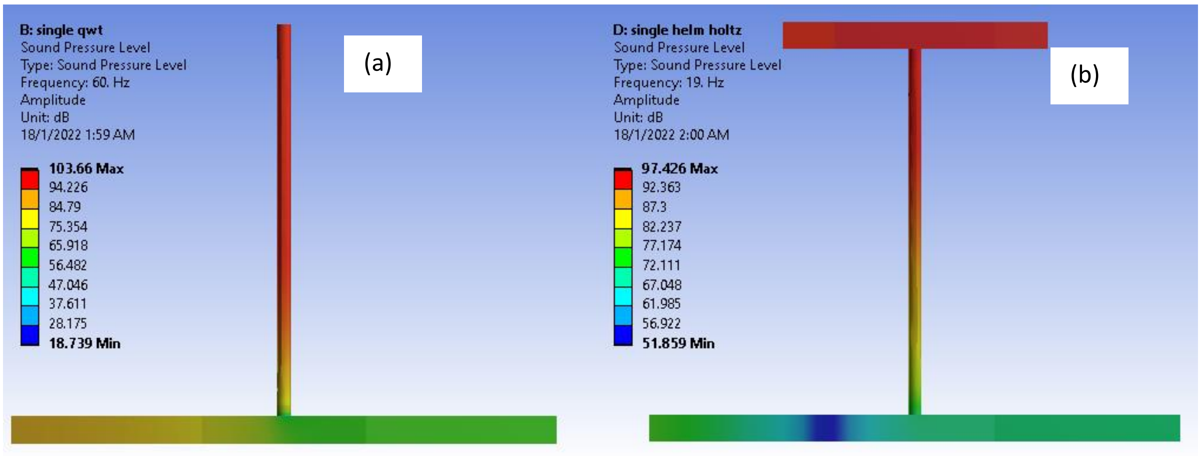

Figure 7. Sound pressure level at the first natural frequency for (a) single QWT at 60 Hz and (b) single HR at 19 Hz.

4.2 Effect of Multiple Resonator Silencers

Figure 8 shows the transmission loss results at the first natural frequency, i.e. 60 Hz by comparing the use of single, double and a triple QWTs installed on the ducting system. The outcome demonstrates that by increasing the number of QWT, the higher value of transmission loss can be achieved. The triple QWT displays the highest transmission loss of 76 dB, followed by the double QWT of 56 dB and the single QWT of 19 dB. A similar pattern is observed in the transmission loss result for Helmholtz resonator as shown in Figure 10.

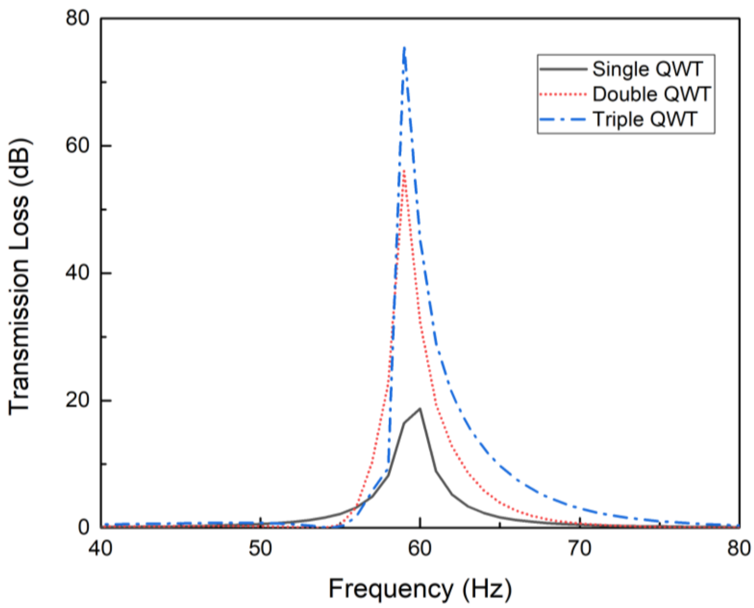

Figure 8. Influence of multiple QWTs on perceived transmission loss.

Similarly, it can be observed in the sound pressure level at 60 Hz along the axis of a main duct with attached multiple QWT as displayed in Figure 9. The results indicate that the sound pressure levels at the main duct outlet decrease significantly as the number of QWTs increases, where the maximum percentage reduction is obtained almost 55% for a triple QWT. These results again prove that increasing the number of quarter wavelength tubes can make the device perform better in noise attenuation.

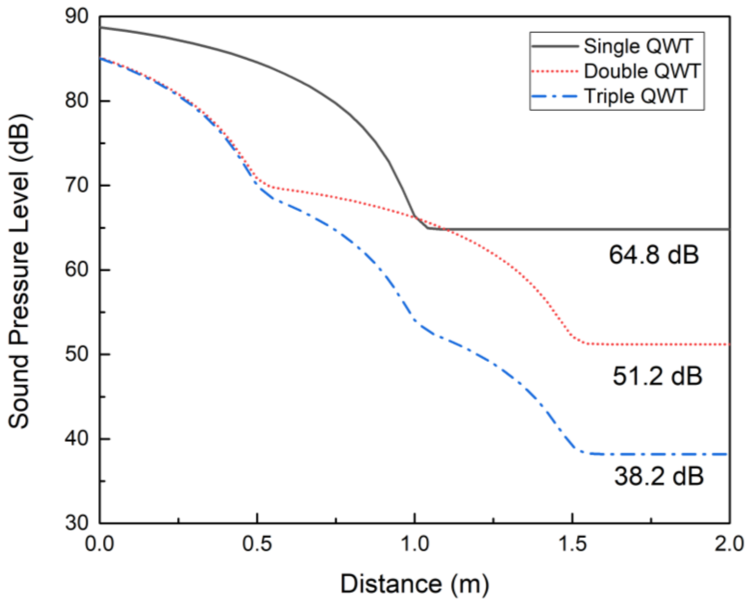

Figure 9. Sound pressure level at 60 Hz along the axis of a duct with attached multiple QWTs.

On the other hand, for Helmholtz resonator, the first natural of the system was to be happened at 20 Hz, where the transmission loss increase to the highest peak as shown in Figure 10. As it can be seen from Figure 10, the triple HR shows the highest transmission loss of 32 dB, followed by double HR of 25 dB and single HR of 13 dB at the 20 Hz. The comparison of the transmission loss between the HR and QWT devices attached to a main duct is shown in Table 2. The result shows that the QWT achieves twice the value of transmission loss compared to HR.

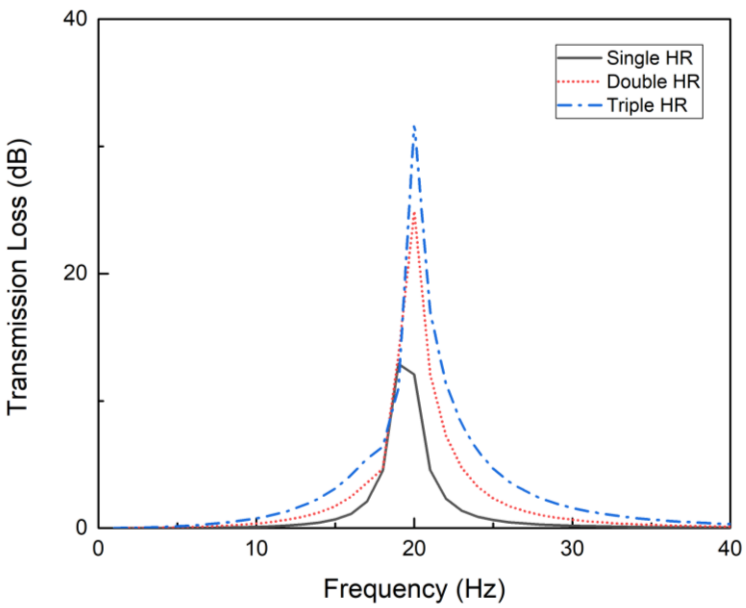

Figure 10. Influence of multiple HRs on perceived transmission loss.

Figure 11 shows the sound pressure level along the axis of a main duct with attached multiple HR. Similarly, with the QWT, the results show that the sound pressure levels along the main duct reduce significantly and stabilize after passing through Helmholtz resonator at 20 Hz. The reduction in SPL becomes more pronounced as the number of HRs increases. The lowest SPL obtained at the duct outlet was 52 dB when triple HRs were attached to the main duct, and this reduction reached almost 35%.

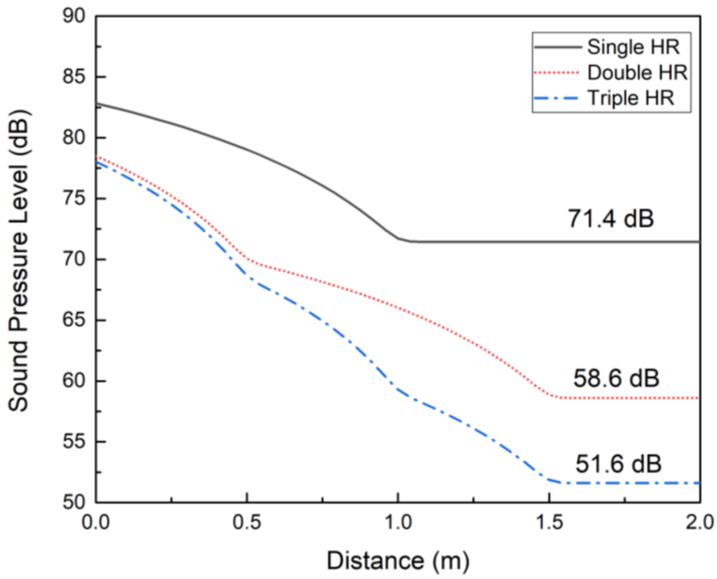

Figure 11. Sound pressure level at 60 Hz along the axis of a duct with attached multiple HRs.

Table 2 A Comparison of Transmission Loss Between the QWT and HR

	QWT at First Natural Frequency 60 Hz			HR at First Natural Frequency 20 Hz		
	Single	**Double**	**Triple**	**Single**	**Double**	**Triple**
Transmission Loss (dB)	18.7	56.0	75.8	12.9	24.9	31.9

5. CONCLUSION

The installation of resonator silencers such as quarter wavelength tube and Helmholtz resonator on the main duct system was successfully prepared in this study. Preliminary result of harmonic analysis indicates that both resonator silencers perform well in attenuating sound in the duct system. The quarter wavelength tube achieves the highest SPL reduction at the system's natural frequency, while Helmholtz resonator reduces the sound effectively over a broad frequency range. Subsequently when the duct is attached with multiple resonators, the sound pressure level can be further reduced by the installation of a triple resonator silencers attachment. The transmission loss obtained by a multiple quarter wavelength tube is higher than that of Helmholtz resonator. Overall, this study reveals that multiple resonator silencers attached to the duct system proved to be more effective in noise suppression.

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